Quantifying Sediment Volume Inhomogeneity for Modeling High-Frequency Acoustic Backscatter

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Thrust Category: High-Frequency

LONG-TERM GOAL

As part of ONR's Sediment Acoustics EXperiment (SAX 99), the long-term goal of this research is to develop an approach for deriving acoustically relevant, high-resolution descriptions of seafloor sediments for modeling high-frequency sound scattering.

OBJECTIVES

The primary objectives of this research are as follows:

1. Provide a quantitative preassessment of the three-dimensional structure of sandy sediments in preparation for SAX99 (Oct-Nov 1999) off Fort Walton Beach, FL. To do this, existing data for similar sediments collected during the 1993 Coastal Benthic Boundary Layer (CBBL) exercise off Panama City will be used.

2. Derive realistic sediment input parameters for the development of accurate acoustic scattering models. Investigations include construction of high-resolution density profiles and characterization of volume inhomogeneity.

APPROACH

X-ray computed tomography (X-ray CT) is being used for core characterization in this research. Developed over 30 years ago by the medical industry to generate cross-sectional X-ray images of the brain, X-ray CT is a powerful analytical technique, well suited for high-resolution geoacoustic characterization of marine sediment cores. It is non-destructive and quantitative, has sub-millimeter resolution, and permits two- and three-dimensional visualization of sediment structure.

Numerical modeling assistance for this research has been provided by Dr. Dajun Tang of the Applied Physics Laboratory (University of Washington, Seattle, WA) and Dr. Anthony P. Lyons of the SACLANT Undersea Research Centre (La Spezia, Italy).

WORK COMPLETED

1. Analysis of the Panama City sediments has been completed and the results in terms of the power spectra of density variability have been published in the *Journal of the Acoustical Society of America* (Tang and Orsi, 2000a). This analysis has been recently extended to include other sediment types, such as high-porosity muds and carbonates, and presented at the *Fifth European Conference on Underwater Acoustics* in Lyon, France (Tang and Orsi, 2000b).

2. A calibration procedure has been developed for CT analyses of marine sediments and published in *Geo-Marine Letters* (Orsi and Anderson, 1999).

3. Several existing CT data sets were used to examine the impact of a thin layer of varying density on high-frequency reflection, forward loss, and backscatter of acoustic plane waves from the seafloor. This analysis has been published in the *IEEE Journal of Ocean Engineering* (Lyons and Orsi, 1998).

4. SAX99 cores collected by divers for CT analysis have been scanned and analysis is underway.

RESULTS

1. Spectral analysis of the sandy Panama City sediments reveals three mechanisms causing density variability: shell fragments, mud inclusions, and the intrinsic variability of the sand matrix (consistent with a Gaussian distribution). Shells and mud inclusions dominate the low-wavenumber portion of the spectrum, whereas intrinsic matrix variability dominates the high-wavenumber portion. The inferred spectrum is well described using an analytical model with two power-law terms. The exponent of the first power-law term is much higher than previously believed. In the case of backscatter, the relationship between the power spectrum and acoustic frequency shows that between 10-100 kHz, backscatter will be strongly influenced by the presence of the shell fragments and mud inclusions, whereas intrinsic variability influences backscatter at frequencies above 400 kHz. In addition, when the frequency is lower than 70 kHz, the backscattering cross section behaves like that of a Rayleigh scatterer.

2. A calibration technique was developed for converting CT numbers to equivalent sediment bulk densities. Derived using artificial samples and confirmed with natural marine sediment samples, the correlation for carbonate-free samples is extremely strong and valid over densities from 1.0 g/cm^3 to 2.2 g/cm^3. A similar analysis of carbonate samples and sediment cores was also strongly linear but offset from the silica curve, a result of differing sediment composition. (Further development of the CT number-carbonate relationship would be a valuable research topic.) Density resolution of the CT scanner is excellent and estimated to be 0.005 g/cm^3. Greater precision is not warranted because density variations in this range of sensitivities can be affected significantly by thermal fluctuations.

3. A functional form for density stratification was devised using CT to quantify the impact of a thin layer of varying density on high-frequency acoustic response. Inclusion of a high-resolution density profile adds a strong frequency dependence to estimates of the reflection coefficient and forward loss, and the largest effect on total scattering strength is near normal incidence where returns are dominated by interface scattering. The effect of the density profile on the strength of acoustic returns suggests that

care should be exercised when using high-frequency systems for measuring sediment properties, especially near-normal incidence. (From Lyons and Orsi, 1998).

4. Five diver cores were collected from the SAX99 study area for CT analysis. After some serious setbacks (including a scanner malfunction and the Bonfire tragedy at Texas A&M), the cores were scanned every 3 mm, using a 2-mm-thick X-ray beam. Each scan is a 512 x 512 voxel matrix, with every voxel assigned a value, a CT number, that is directed related to bulk density. The (x, y, z) dimensions of a voxel are 0.25 mm x 0.25 mm x 2 mm, representing a sediment volume of 0.125 mm^3. Preliminary analysis of the CT imagery reveals a remarkably uniform structure with only a few isolate volume inhomogeneities, primarily shell debris (Figure 1). However, CT data from many of the cores exhibit a "ringed" density structure, suggesting poor core quality caused by compaction. Although at least some of the observed structure may be a scanner artifact known as beam hardening (a density cupping effect), review of water scans taken for calibration purpose showed a minimal effect. Presently, the magnitude of the disturbance is being evaluated.

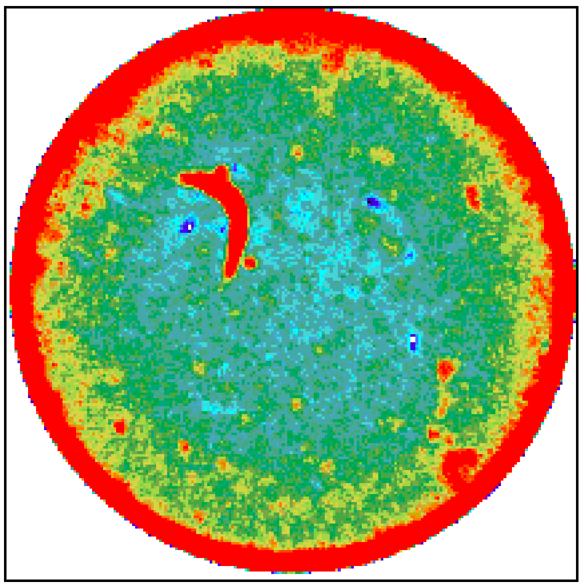

Figure 1. Horizontal CT scan from Core D87. Average density is approximately 1600 g/cm^3. Note the shell fragment, scattered smaller pieces of shell debris, the essentially featureless matrix, and the slight densification along the periphery of the core.

IMPACT/APPLICATIONS

Development of accurate, quantitative, and appropriately scaled seafloor descriptions via CT analysis will eliminate modeling ambiguities associated with uncertain sediment structure.

TRANSITIONS

Historically, one of the more difficult tasks in modeling the interaction of high-frequency sound with the seafloor has been developing realistic descriptions of the sediments with all their complexity. This complexity is often readily apparent in any sediment core or x-radiograph. Fortunately, CT analysis is uniquely suited to enable the transition of qualitative and semi-quantitative geologic information to the quantitative input parameters needed by acousticians for modeling acoustic scattering.

RELATED PROJECTS

In related efforts, I participated in the SACLANT Centre's FSG-DERA-JRP-2 experiment in the Bay of La Spezia (Co-Chief Scientists: T. Lyons and E. Pouliquen). For this exercise, CT analysis of diver-collected horizontal cores was used to examine volume inhomogeneity in both the vertical and horizontal dimensions (Figure 2). Results were presented at the *Fifth European Conference on Underwater Acoustics* (Pouliquen et al., 2000).

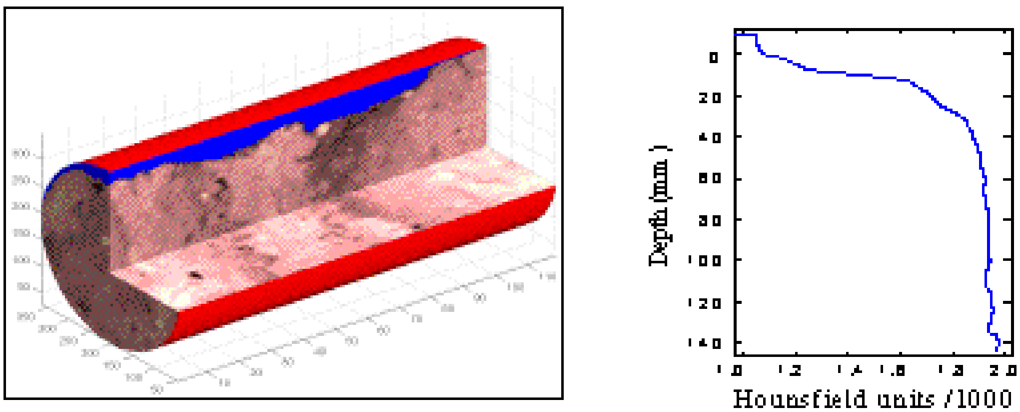

Figure 2. False color 3-D reconstruction of horizontal core at Porto Venere, Italy (left). Density profile obtained from the X-ray tomography technique (right).

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